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(54) Title: MUTANTS OF GREEN FLUORESCENT PROTEIN

(57) Abstract: The present invention provides novel engineered derivatives of green fluorescent protein (GFP) which have an amino acid sequence which is modified by amino acid substitution compared with the amino acid sequence of wild type Green Fluorescent Protein. The modified GFPs exhibit enhanced fluorescence relative to wtGFP when expressed in non-homologous cells at temperatures above 30 °C, and when excited at about 490 nm compared to the parent proteins, i.e. wtGFP. An example of a preferred protein is F64L-S175G-E222G-GFP. The modified GFPs provide a means for detecting GFP reporters in mammalian cells at lower levels of expression and/or increased sensitivity relative to wtGFP. This greatly improves the usefulness of fluorescent proteins in studying cellular functions in living cells.



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## MUTANTS OF GREEN FLUORESCENT PROTEIN

The present invention relates to novel variants of the fluorescent protein GFP having improved fluorescence properties.

5

The use of Green Fluorescent Protein (GFP) derived from *Aequorea victoria* has revolutionised research into many cellular and molecular-biological processes. GFP allows researchers to label proteins within cells with an intrinsic fluor, so obviating the requirement to perform chemical  
10 labelling of proteins, and allowing development of assays of biological processes in intact living cells.

US 5491084 describes the use of GFP as a biological reporter. Early applications of GFP as a biological reporter (Chalfie et al. Science, (1994),  
15 263, 802-5; Chalfie, et al, Photochem.Photobiol., (1995), 62(4), 651-6) used wild type (native) GFP (wtGFP), but these studies quickly demonstrated two areas of deficiency of wtGFP as a reporter for use in mammalian cells. Firstly, the protein being derived from a poikilothermic marine organism does not undergo protein folding efficiently when expressed in mammalian cells  
20 cultured at 37 °C, resulting in weak fluorescence. Secondly, the spectral characteristics of the wtGFP are not ideally suited to use as a cellular reporter, requiring excitation with electromagnetic radiation in the near-UV range, which is potentially damaging to living cells.

25 Consequently, significant effort has been expended to produce variant mutated forms of GFP with properties more suitable for use as an intracellular reporter.

A number of mutated forms of GFP with altered spectral properties  
30 have been described. A variant-GFP (Heim et al. (1994) Proc.Natl.Acad.Sci. 91, 12501) contains a Y66H mutation which blue-shifts the excitation and

emission spectrum of the protein. However, this protein is only weakly fluorescent and requires potentially damaging UV excitation.

A further mutant of GFP (Heim et al, Nature, (1995), 373, 663-664) contains a S65T mutation which red-shifts the optimum excitation and emission wavelengths relative to wtGFP and which is 4-6 fold brighter than wtGFP when expressed as a recombinant protein at 25 °C. However, this variant does not yield bright fluorescence when expressed in hosts cultured at 37 °C.

Ehrig et al (FEBS Lett., (1995), 367, 163-6) describe two mutations of GFP, T203I and E222G, which individually delete one of the excitation maxima of wtGFP. The E222G mutation deletes the near-UV excitation peak at 395 nm and produces a red-shift in the excitation peak at 475 nm to 481 nm. The emission peak for this mutant protein is at 506 nm.

WO96/27675 describes two variant GFPs, obtained by random mutagenesis and subsequent selection for brightness, which contain the mutations V163A and V163A + S175G, respectively. These variants were shown to produce more efficient expression in plant cells relative to wtGFP and to increase the thermotolerance of protein folding. The double mutant V163A + S175G was observed to be brighter than the variant containing the single V163A mutant alone; however this mutant exhibits an undesirable blue-shifted excitation peak.

A further mutant, termed cycle-3, generated by molecular evolution through DNA shuffling (Cramer, A. et al, Nature Biotechnology, (1996), 14, 315-9) is available commercially from Invitrogen Inc. Cycle-3-GFP contains three mutations (F99S + M153T + V163A) which increase whole cell fluorescence approximately 42 fold when compared with wtGFP. However,

this mutant retains the near-UV excitation maximum of the wtGFP, making it less suitable as a reporter for use in living cells.

The above mutations effectively address some of the spectral  
5 deficiencies of wtGFP as a biological reporter in providing variant forms of GFP which are compatible with lower energy excitation and which emit at wavelengths compatible with detection instrumentation commonly in use for measuring biological reporters. However, such mutations do not address the  
10 problem of inefficient folding and chromophore formation when wtGFP or spectral variants are expressed in hosts requiring growth at temperatures significantly greater than ambient.

US 6172188 describes variant GFPs wherein the amino acid in  
position 1 preceding the chromophore has been mutated to provide an  
15 increase of fluorescence intensity. Such mutations include F64I, F64V, F64A, F64G and F64L, with F64L being the preferred mutation. These mutants result in a substantial increase in the intensity of fluorescence of GFP without shifting the excitation and emission maxima. F64L-GFP has been shown to yield an approximate 6-fold increase in fluorescence at 37 °C  
20 due to shorter chromophore maturation time.

In addition to the single mutants or randomly derived combinations of mutations described above, a variety of mutant-GFPs have been created which contain two or more mutations deliberately selected from those  
25 described above and other mutations, and which seek to combine the advantageous properties of the individual mutations to produce a protein with expression and spectral properties which are suited to use as a sensitive biological reporter in mammalian cells.

30 One mutant, commonly termed EGFP, available commercially from Clontech Inc., contains the mutations F64L and S65T (Cormack, B.P. et al,

Gene, (1996), 173, 33-38). These mutations when combined, confer an approximate 35-fold increase in brightness over wtGFP and the spectral characteristics permit excitation and detection of EGFP with commonly used fluorescein excitation (488 nm) and emission filters (505 nm–530 nm).

- 5 EGFP has been optimised for expression in mammalian systems, having been constructed with preferred mammalian codons.

US 6194548 discloses GFPs with improved fluorescence and folding characteristics at 37 °C that contain, at least, the changes F64L and V163A  
10 and S175G. A further mutant GFP containing the F64L, S65T and V163A mutations has been described (Cubitt, A.B. et al, Methods in Cell Biology, (1999), 58, 19-29).

US 6077707 describes a blue fluorescent protein (BFP) containing the  
15 F64L mutation in combination with Y66H and US 6194548 describes a further BFP containing the F64L, Y66H, Y145F and L236R substitutions.

The present invention provides novel engineered derivatives of green fluorescent protein (GFP) which exhibit enhanced fluorescence relative to  
20 wtGFP when expressed in non-homologous cells at temperatures above 30°C, and when excited at about 490 nm compared to the parent proteins, i.e. wtGFP. Mutant GFPs according to the invention provide a means for detecting GFP reporters in mammalian cells at lower levels of expression and/or increased sensitivity relative to wtGFP. This greatly improves the  
25 usefulness of fluorescent proteins in studying cellular functions in living cells. The multiply-mutated GFPs of this invention have fluorescence properties which are not predictable from the properties of the individual mutations when studied in isolation. Furthermore, it has surprisingly been found that certain GFPs according to the present invention, which do not contain any  
30 mutations in the chromophore region relative to wtGFP, exhibit enhanced fluorescence compared with mutant GFPs described previously.

In a first aspect of the invention, there is provided a fluorescent protein which is derived from Green Fluorescent Protein (GFP) or any functional GFP analogue and has an amino acid sequence which is modified by amino acid substitution compared with the amino acid sequence of wild type Green Fluorescent Protein said modified fluorescent protein comprising:

- i) an amino acid substitution at position F64;
- ii) a single amino acid substitution at a position selected from the group consisting of positions S65 and E222; and
- iii) an amino acid substitution at position S175;

wherein said modified GFP has a different excitation spectrum and/or emission spectrum compared with wild type GFP.

Suitably, the amino acid F at position 64 may be substituted by an amino acid selected from the group consisting of L, I, V, A and G, thereby providing F64L, F64I, F64V, F64A, or F64G substitutions. In a preferred embodiment of the first aspect, the amino acid F is substituted by L at position 64.

Suitably, the amino acid S at position 175 may be substituted by an amino acid selected from the group consisting of G, A, L, I and T, thereby providing S175G, S175A, S175L, S175I and S175T substitutions. In a preferred embodiment of the first aspect, the amino acid S is substituted by G at position 175.

In embodiments where the amino acid S at position 65 is substituted, it is suitably substituted by an amino acid selected from the group consisting of G, A, L, C, V, I and T, thereby providing S65G, S65A, S65L, S65C, S65V, S65I or S65T substitutions. Preferably, the amino acid substitution at position 65 is the S65T substitution.

In embodiments where the amino acid E at position 222 is substituted, it is suitably substituted by an amino acid selected from the group consisting of G, A, V, L, I, F, S, T, N and Q, thereby providing E222G, E222A, E222V, E222L, E222I, E222F, E222S, E222T, E222N or E222Q substitutions.

5 Preferably, the amino acid substitution at position 222 is the E222G substitution.

Suitably, the novel fluorescent proteins exhibit high fluorescence in cells expressing them when said cells are incubated at a temperature of 30  
10 °C or above, preferably at a temperature of from 32 °C to 39 °C, more preferably from 35 °C to 38 °C and most preferably at a temperature of about 37 °C.

Preferably, the fluorescent protein according to the first aspect has an  
15 amino acid sequence which is modified by amino acid substitution compared with the amino acid sequence of wild type Green Fluorescent Protein having the sequence: SEQ ID No.2.

A preferred protein according to the present invention is a protein in  
20 which, in relation to SEQ ID No.2 of GFP, the amino acid F at position 64 has been substituted by L, the amino acid S at position 175 has been substituted by G and the amino acid E at position 222 has been substituted by G, and is shown herein as having the amino acid sequence as set forth in SEQ ID  
No.3.

25

An alternative preferred protein according to the present invention is a protein in which, in relation to SEQ ID No.2 of GFP, the amino acid F at position 64 has been substituted by L, the amino acid S at position 65 has been substituted by T and the amino acid S at position 175 has been  
30 substituted by G, and is shown herein as having the amino acid sequence as set forth in SEQ ID No.4.

Suitably, the GFP or functional GFP-analogue used to derive the fluorescent protein may be obtained from any convenient source. For example, native GFP derived from species of the genus *Aequorea*, suitably  
5 *Aequorea victoria*. The chromophore in wtGFP from *Aequorea victoria* is at positions 65-67 of the predicted primary amino acid sequence (SEQ ID No.2). In a preferred embodiment, the GFP is derived from *Aequorea victoria*.

The modified proteins of the present invention may be produced by  
10 introducing mutations in a sequence of the nucleic acid that encodes the protein. As used herein, a preferred sequence of the gene encoding wtGFP is derived from *Aequorea victoria*, published by Chalfie et al, (Science, (1994), 263, 802-5) disclosed as SEQ ID No.1 (Figure 1). The corresponding amino acid sequence is shown in SEQ ID No.2 (Figure 2). Alternative sequences of  
15 the GFP gene may be used, for example, the nucleotide (and predicted amino acid) sequences of the GFP gene described by Prasher et al, (Gene (1992), 111, 229) and the sequences as disclosed in WO 97/11094. In addition, alternative gene sequences that encode the fluorescent protein may incorporate a consensus Kozak nucleotide sequence (Kozak, M., Cell (1986),  
20 44, 283), or preferred mammalian codons, to provide improved translation in mammalian systems. The nucleotide sequence corresponding to the fluorescent protein may also encode useful restriction enzyme sites and additional elements such as target sites for enzymes and purification tags. Methods for incorporation of a Kozak region, preferred mammalian codons,  
25 restriction enzyme sites, enzyme sites and purification tags are well known in the art and may result in the incorporation of amino acid residues and a change in numbering of amino acid residues in the fluorescent protein relative to the wtGFP numbering in the sequence provided.

30 Herein, the abbreviations used for the amino acids are those stated in J.Biol.Chem., (1968), 243, 3558.



In a second aspect of the invention, there is provided a fusion compound comprising a protein of interest fused to a fluorescent protein which is derived from Green Fluorescent Protein (GFP) or any functional GFP analogue and has an amino acid sequence which is modified by amino acid substitution compared with the amino acid sequence of wild type Green Fluorescent Protein said modified fluorescent protein comprising:

- i) an amino acid substitution at position F64;
- ii) a single amino acid substitution at a position selected from the group consisting of positions S65 and E222; and
- iii) an amino acid substitution at position S175;

wherein said modified GFP has a different excitation spectrum and/or emission spectrum compared with wild type GFP.

In the context of the present invention, the term "protein of interest" is intended also to encompass polypeptides and peptide fragments. Examples of such proteins of interest include: NF $\kappa$ B and subunits thereof, RAC1, PLC domains, MAPKAP2, PKC, Cytochrome C, RHO,  $\beta$ -actin, STAT6, protein kinase C isotypes, LAMP1/2 TGN, ATP7A TGN and GLUT4.

In a third aspect of the present invention there is provided a nucleic acid molecule comprising a nucleotide sequence encoding a fluorescent protein which is derived from Green Fluorescent Protein (GFP) or any functional GFP analogue and has an amino acid sequence which is modified by amino acid substitution compared with the amino acid sequence of wild type Green Fluorescent Protein said modified fluorescent protein comprising:

- i) an amino acid substitution at position F64;
- ii) a single amino acid substitution at a position selected from the group consisting of positions S65 and E222; and
- iii) an amino acid substitution at position S175;

wherein said modified GFP has a different excitation spectrum and/or emission spectrum compared with wild type GFP.

Preferably, the nucleic acid molecule according to the third aspect  
5 encodes a fluorescent protein having an amino acid sequence which is modified by amino acid substitution compared with the amino acid sequence of wild type Green Fluorescent Protein having the sequence: SEQ ID No.2.

In a particular embodiment of the third aspect, the nucleic acid  
10 molecule comprises a nucleotide sequence encoding a fluorescent protein derived from Green Fluorescent Protein (GFP) or any functional GFP analogue according to the invention fused to a nucleotide sequence encoding a protein of interest.

15 Preferably, the nucleic acid molecule is a construct comprising a DNA sequence.

Preferably, the nucleic acid molecule encodes a fluorescent protein having an amino acid sequence selected from the group consisting of SEQ ID  
20 No.3 and SEQ ID No.4.

As is well known, a single amino acid may be encoded by more than one nucleotide codon and thus each of the above nucleotide sequences may be modified to produce an alternative nucleotide sequence that encodes the  
25 same peptide. Thus, the preferred embodiments of the invention include alternative DNA sequences that encode the preferred proteins as previously described. It is to be understood that the preferred proteins (and the nucleic acid sequences from which they are derived), may include additional residues, particularly N- and C-terminal amino acids, or 5'- or 3'-nucleotide  
30 sequences, and still be essentially as described herein.

Suitably, the DNA construct encoding the novel fluorescent proteins may be prepared synthetically by established methods, e.g. the phosphoramidite method described by Beaucage and Caruthers, (Tetrahedron Letters (1981), 22, 1859-1869), or the method described by Matthes et al.,  
5 (EMBO Journal (1984), 3, 801-805). According to the phosphoramidite method, oligonucleotides are synthesized, e.g. in an automatic DNA synthesizer, purified, annealed, ligated and cloned into suitable vectors.

The DNA construct encoding the fluorescent protein may also be  
10 prepared by recombinant DNA methodology, for example cDNA cloning. See for example, Sambrook, J. et al (1989) Molecular Cloning - A Laboratory Manual, Cold Spring Harbor Laboratory Press.

The DNA construct may also be prepared by polymerase chain reaction  
15 (PCR) using specific primers, for instance as described in US 4683202 or by Saiki et al (Science (1988), 239, 487-491). A recent review of PCR methods may be found in PCR Protocols, (1990), Academic Press, San Diego, California, USA.

20 The gene sequence encoding the fluorescent protein may be joined in-frame with a gene encoding the protein of interest and the desired fusion protein produced when inserted into an appropriate expression vector. For example, polymerase chain reaction or complementary oligonucleotides may be employed to engineer a polynucleotide sequence corresponding to the  
25 fluorescent protein, 5' or 3' to the gene sequence corresponding to the protein of interest. Alternatively, the same techniques may be used to engineer a polynucleotide sequence corresponding to the fluorescent protein sequence 5' or 3' to the multiple cloning site of an expression vector prior to insertion of a gene sequence encoding the protein of interest. The  
30 polynucleotide sequence corresponding to the fluorescent protein sequence may comprise additional nucleotide sequences to include cloning sites,

linkers, transcription and translation initiation and/or termination signals, labelling and purification tags.

In a fourth aspect, there is provided an expression vector comprising  
5 suitable expression control sequences operably linked to a nucleic acid molecule according to the present invention. The DNA construct of the invention may be inserted into a recombinant vector, which may be any vector that may conveniently be subjected to recombinant DNA procedures. The choice of vector will often depend on the host cell into which it is to be  
10 introduced. Thus, the vector may be an autonomously replicating vector, ie. a vector which exists as an extrachromosomal entity, the replication of which is independent of chromosomal replication, eg. a plasmid. Alternatively, the vector may be one which, when introduced into a host cell, is integrated into the host cell genome and replicated together with the  
15 chromosome(s) into which it has been integrated.

The vector is preferably an expression vector in which the DNA sequence encoding a fluorescent protein of the invention is operably linked to additional segments required for transcription of the DNA. In general, the  
20 expression vector is derived from plasmid or viral DNA, or may contain elements of both. The term, "operably linked" indicates that the segments are arranged so that they function in concert for their intended purposes, e.g. transcription initiates in a promoter and proceeds through the DNA sequence coding for the fluorescent protein of the invention.

25

The promoter may be any DNA sequence which shows transcriptional activity in a suitable host cell of choice, (eg. a bacterial cell, a mammalian cell, a yeast cell, or an insect cell) for expressing a fluorescent protein. The promoter may be derived from genes encoding proteins either homologous or  
30 heterologous to the host cell.

Examples of suitable promoters for directing the transcription of the DNA sequence encoding the fluorescent protein of the invention in mammalian cells are the CMV promoter (US 5168062, US5385839), Ubiquitin C promoter (Wulff, M. et al., FEBS Lett. (1990), 261, 101-105), SV40 promoter (Subramani et al., Mol. Cell Biol. (1981), 1, 854-864) and MT-1 (metallothionein gene) promoter (Palmiter et al., Science (1983), 222, 809-814). An example of a suitable promoter for use in insect cells is the polyhedrin promoter (US 4745051; Vasuvedan et al., FEBS Lett., (1992) 311, 7-11). Examples of suitable promoters for use in yeast host cells include promoters from yeast glycolytic genes (Hitzeman et al., J. Biol. Chem., (1980), 255, 12073-12080; Alber and Kawasaki, J. Mol. Appl. Gen., (1982), 1, 419-434) or alcohol dehydrogenase genes (Young et al., in Genetic Engineering of Microorganisms for Chemicals (Hollaender et al, eds.), Plenum Press, New York, 1982), or the TPI1 (US 4599311) or ADH2-4c (Russell et al., Nature, (1983), 304, 652-654) promoters.

Examples of suitable promoters for use in bacterial host cells include the promoter of the *Bacillus stearothermophilus* maltogenic amylase gene, the *Bacillus licheniformis* alpha-amylase gene, the *Bacillus amyloliquefaciens* BAN amylase gene, the *Bacillus subtilis* alkaline protease gene, or the *Bacillus pumilus* xylosidase gene, or the phage Lambda PR or PL promoters or the *Escherichia coli lac*, *trp* or *tac* promoters.

The DNA sequence encoding the novel fluorescent proteins-of the invention may also, if necessary, be operably connected to a suitable terminator, such as the human growth hormone terminator (Palmiter et al., op. cit.) or (for fungal hosts) the TPI1 (Alber and Kawasaki, op. cit.) or ADH3 (McKnight et al., op. cit.) terminators. The vector may further comprise elements such as polyadenylation signals (e.g. from SV40 or the adenovirus 5 Elb region), transcriptional enhancer sequences (e.g. the SV40 enhancer)

and translational enhancer sequences (e.g. the ones encoding adenovirus VA RNAs).

5 The vector may further comprise a DNA sequence enabling internal ribosomal entry and expression of two proteins from one bicistronic transcript mRNA molecule. For example, the internal ribosomal entry sequence from the encephalomyocarditis virus (Rees S, et al, BioTechniques (1996), 20, 102-110 and US 4937190).

10 The recombinant vector may further comprise a DNA sequence enabling the vector to replicate in the host cell in question. An example of such a sequence (when the host cell is a mammalian cell) is the SV40 origin of replication.

15 When the host cell is a yeast cell, examples of suitable sequences enabling the vector to replicate are the yeast plasmid 2 $\mu$  replication genes REP 1-3 and origin of replication.

The vector may also comprise selectable markers, such as a gene that  
20 confers resistance to a drug, e.g. ampicillin, kanamycin, tetracyclin, chloramphenicol, puromycin, neomycin or hygromycin.

The procedures used to ligate the DNA sequences coding for the fluorescent protein of the invention, the promoter and optionally the  
25 terminator and/ or targeting sequence, respectively, and to insert them into suitable vectors containing the information necessary for replication, are well known to persons skilled in the art (eg. Sambrook et al., op.cit.).

In a fifth aspect of the invention, there is provided a host cell  
30 transformed or transfected with a DNA construct comprising an expression vector according to the present invention.

The DNA construct or the recombinant vector of the invention is suitably introduced into a host cell which may be any cell which is capable of expressing the present DNA construct and includes bacteria, yeast and  
5 higher eukaryotic cells (Unger, T.F., The Scientist (1997), 11(17), 20-23; Smith, C., The Scientist (1998), 12(22): 20; Smith, C., The Scientist (1998), 12(3), 18; Fernandez, J.M. & Hoeffler, J.P., Gene Expression Systems- using nature for the art of expression, Academic Press 1999).

10 Examples of bacterial host cells which, on cultivation, are capable of expressing the DNA construct of the invention are Gram-positive bacteria, eg. species of *Bacillus* or Gram-negative bacteria such as *E. coli*. The transformation of the bacteria may be effected by using competent cells in a manner known per se (cf. Sambrook et al., supra).

15 Examples of suitable mammalian cell lines are the HEK293 and the HeLa cell lines, primary cells, and the COS (e.g. ATCC CRL 1650), BHK (eg. ATCC CRL 1632, ATCC CCL 10), CHL (e.g. ATCC CCL39) or CHO (eg. ATCC CCL 61) cell lines. Methods of transfecting mammalian cells and  
20 expressing DNA sequences introduced in the cells are described in eg. Kaufman and Sharp, J. Mol. Biol., (1982), 159, 601-621; Southern and Berg, J. Mol. Appl. Genet., (1982), 1, 327-341; Loyter et al., Proc. Natl. Acad. Sci. USA, (1982), 79, 422-426; Wigler et al., Cell, (1978), 14, 725; Corsaro and Pearson, Somatic Cell Genetics, (1981), 7, 603, Graham and  
25 van der Eb, Virology (1973), 52, 456; and Neumann et al., EMBO J., (1982), 1, 841-845.

Examples of suitable yeast cells include cells of *Saccharomyces* spp. or *Schizosaccharomyces* spp., in particular strains of *Saccharomyces cerevisiae*  
30 or *Saccharomyces kluyveri*. Methods for transforming yeast cells with heterologous DNA and producing heterologous polypeptides therefrom are

described, e.g. in US 4599311, US 4931373, US 4870008, US 5037743, and US 4845075, all of which are hereby incorporated by reference.

Transformed cells are selected by a phenotype determined by a selectable marker, commonly drug resistance or the ability to grow in the absence of a particular nutrient, e.g. leucine. A preferred vector for use in yeast is the POT1 vector disclosed in US 4931373. The DNA sequence encoding the fluorescent protein of the invention may be preceded by a signal sequence and optionally a leader sequence, e.g. as described above. Further examples of suitable yeast cells are strains of *Kluyveromyces*, such as *K. lactis*, *Hansenula*, e.g. *H. polymorpha*, or *Pichia*, e.g. *P. pastoris* (cf. Gleeson et al., J. Gen. Microbiol., (1986), 132, 3459-3465; US 4882279).

Transformation of insect cells and production of heterologous polypeptides therein may be performed as described in US 4745051; US 4879236; US 5155037; US 5162222; EP 397485, all of which are incorporated herein by reference. The insect cell line used as the host may suitably be a *Lepidoptera* cell line, such as *Spodoptera frugiperda* cells or *Trichoplusia ni* cells (cf. US 5077214). Culture conditions may suitably be as described in, for instance, WO 89/01029 or WO 89/01028, or any of the aforementioned references.

In a sixth aspect, the invention provides a method for preparing a Green Fluorescent Protein (GFP) or a functional GFP analogue according to the present invention, the method comprising cultivating a host cell transformed or transfected with a nucleotide sequence according to the invention and obtaining therefrom the polypeptide expressed by said nucleotide sequence.

Suitably, the transformed or transfected host cells as described above are cultured in a suitable nutrient medium under conditions permitting the expression of a DNA construct according to the invention, after which the



cells may be used in the screening method of the invention. Alternatively, the cells may be disrupted after which cell extracts and/or supernatants may be analysed for fluorescence and/ or used to purify the GFP or functional GFP analogue of the invention.

5

The medium used to culture the cells may be any conventional medium suitable for growing the host cells, such as minimal or complex media containing appropriate supplements. Suitable media are available from commercial suppliers or may be prepared according to published protocols (eg. in catalogues of the American Type Culture Collection; Sambrook et al., supra).

10

For example, a fusion protein comprising glutathione S-transferase (GST) and GFP can be constructed and expressed in *E. coli*. The GFP may be joined in-frame to the C-terminus of GST in a pGEX plasmid vector (Amersham Pharmacia Biotech). Recombinant production of the fusion protein is carried out utilising a standard *E. coli* expression host, followed by purification employing glutathione affinity chromatography and removal of the GST tag by proteolytic cleavage.

15

20

In a seventh aspect of the present invention, there is provided a method of measuring the expression of a protein of interest in a cell. The method comprises: i) introducing into a cell a nucleic acid molecule comprising a nucleotide sequence encoding a fluorescent protein which is derived from Green Fluorescent Protein (GFP) or any functional GFP analogue according to the present invention said nucleic acid molecule being operably linked to and under the control of an expression control sequence which moderates expression of said protein of interest; ii) culturing the cell under conditions suitable for the expression of the protein of interest; and iii) detecting the fluorescence emission of the Green Fluorescent Protein (GFP) or

25

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a functional GFP analogue as a means of measuring the expression of the protein of interest.

In an eighth aspect of the present invention, there is provided a  
5 method of determining the cellular and/or extracellular localisation of a  
protein of interest which method comprises:  
i) introducing into a cell a nucleic acid molecule comprising a nucleotide  
sequence encoding a Green Fluorescent Protein (GFP) or a functional GFP  
analogue according to the invention fused to a nucleotide sequence encoding  
10 a protein of interest, said nucleic acid molecule being operably linked to and  
under the control of a suitable expression control sequence;  
ii) culturing said cell under conditions suitable for the expression of said  
protein of interest; and  
iii) determining the cellular and/or extracellular localisation of said protein  
15 of interest by detecting the fluorescence emission by optical means.

The fluorescent proteins of the present invention may also be used in a  
method to detect and compare the effect of a test substance on the  
regulation of expression and/or translocation of two or more different  
20 proteins of interest in a cell. Alternatively, they may be used in a method to  
compare the expression of a protein of interest and the simultaneous activity  
of an expression control sequence in response to a test substance. The  
fluorescent proteins may also be used in a method to compare the activity of  
two or more expression control sequences in a cell in response to a test  
25 substance. Such methods may be performed in the presence and in the  
absence of a test substance whose effect on the process is to be measured.  
For example, one detectable reporter molecule may be used as an internal  
reference and another as a variable marker, since regulated expression of a  
gene can be monitored quantitatively by fusion of an expression control  
30 sequence to a DNA construct encoding, eg. F64L-S175G-E222G-GFP,  
measuring the fluorescence, and normalising it to the fluorescence of a

constitutively expressed spectrally distinct fluorescent molecule. The constitutively expressed spectrally distinct fluorescent molecule, for example BFP, acts as an internal reference.

- 5           Thus, in a ninth aspect of the present invention, there is provided a method of comparing the effect of one or more test substance(s) on the expression and/or localisation of one or more different protein(s) of interest in a cell which method comprises:
- i)       introducing into a cell:
    - 10   a)     a nucleic acid molecule comprising a nucleotide sequence encoding a Green Fluorescent Protein (GFP) or a functional GFP analogue according to the invention optionally fused to a nucleotide sequence encoding a first protein of interest, said nucleic acid molecule being operably linked to and under the control of a first expression control sequence; and optionally,
    - 15   b)     at least one different nucleic acid molecule encoding a protein reporter molecule optionally fused to a different protein of interest, each said nucleic acid molecule being operably linked to and under the control of a second expression control sequence wherein said protein reporter molecule has or is capable of generating an emission signal which is spectrally distinct from that
    - 20   of said Green Fluorescent Protein (GFP) or a functional GFP analogue;
  - ii)     culturing said cells under conditions suitable for the expression of said protein(s) of interest in the presence and absence of said test substance(s);
  - iii)    determining the expression and/or localisation of said protein(s) of interest in said cells by detecting the fluorescence emission by optical means;
  - 25   and
  - iv)     comparing the fluorescence emission obtained in the presence and absence of said test substance(s) to determine the effect of said test substance(s) on the expression and/or localisation of said protein(s) of interest.

In a preferred embodiment of the ninth aspect, samples of said cells in a fluid medium are introduced into separate vessels for each of said test substances to be studied.

5 Preferably, the first and second expression control sequences are different.

Suitably, the protein reporter molecule may be selected from the group consisting of fluorescent proteins and enzymes. Preferred fluorescent  
10 proteins are those which have a spectrally distinguishable emission wavelength compared with the emission wavelength of the fluorescent proteins according to the present invention, for example, BFP. Suitable enzyme reporters are those which are suitable for generating a detectable (eg. a luminescent or fluorescent) signal in a substrate. Suitable  
15 enzyme/substrates include: luciferase/luciferin;  $\beta$ -galactosidase/DDAO galactoside;  $\beta$ -galactosidase/fluorescein di- $\beta$ -D-galactopyranoside; alkaline phosphatase/Atttophos.

In the methods of the invention, the fluorescence of cells transformed  
20 or transfected with the DNA construct according to the invention may suitably be measured by optical means in for example; a spectrophotometer, a fluorimeter, a fluorescence microscope, a cooled charge-coupled device (CCD) imager (such as a scanning imager or an area imager), a fluorescence activated cell sorter, a confocal microscope or a scanning confocal device,  
25 where the spectral properties of the cells in culture may be determined as scans of light excitation and emission.

The fluorescent proteins of the present invention have many additional applications, for example:

- i) Use as a non-toxic marker for selection of transfected cells containing an expression vector encoding at least the fluorescent protein of the invention. The fluorescent emission may be used to isolate transfected cells thereby overcoming the need for selection with toxic molecules such as antibiotics.
- ii) Use as a protein label in living and fixed cells. The novel proteins exhibit strong fluorescence and are a suitable label for proteins present at low concentrations. Since no substrate is needed and visualization of the fluorescent protein does not damage the cells, dynamic analysis can be performed.
- iii) Use as a marker in cell or organelle fusion. By labelling one or more cells or organelles with the novel proteins, for example, F64L-S175G-E222G-GFP, and other cells or organelles with same or another fluor, fusions such as heterokaryon formation can be monitored.
- iv) Translocation of proteins fused to the novel proteins of the invention can be visualised. The translocation of intracellular proteins to a specific organelle can be visualised by fusing the protein of interest to a fluorescent protein, for example, F64L-S175G-E222G-GFP and labelling the organelle with another fluorescent molecule, eg. fluorescent protein. Translocation can then be detected as a spectral shift in the fluorescent proteins in the specific organelle.
- v) Use as a secretion marker. By fusion of a fluorescent protein of the invention to a signal peptide or a peptide to be secreted, secretion may be followed in living cells.
- vi) Use as genetic reporter or protein tag in transgenic animals. Due to the strong fluorescence of the novel proteins, they are suitable as tags for

proteins and gene expression, since the signal to noise ratio is significantly improved over the prior art proteins, such as wild-type GFP.

vii) Use as a cell or organelle integrity marker. By expressing the novel proteins targeted to an organelle, it is possible to calculate the leakage of the protein and use that as a measure of cell integrity.

viii) Use as a transfection marker, and as a marker to be used in combination with FACS sorting (eg. as described in Example 3). Due to the increased brightness of the novel proteins the quality of cell detection and sorting can be significantly improved.

ix) Use as real-time probe working at near physiological concentrations. Since the novel proteins of the present invention are significantly brighter than wtGFP when expressed in cells at about 37 °C and excited with light at about 490 nm, the concentration needed for visualization can be lowered. Target sites for enzymes engineered into the novel proteins, for example F64L-S175G-E222G-GFP, can therefore be present in the cell at low concentrations in living cells. This is important for two reasons: i) the probe must interfere as little as possible with the intracellular process being studied; and ii) the translational and transcriptional apparatus should be stressed minimally.

x) Transposon vector mutagenesis can be performed using the novel proteins as markers in transcriptional and translational fusions. Transposons may be used in microorganisms encoding the novel proteins. The transposons may be constructed for translational and transcriptional fusion to be used for screening for promoters. Transposon vectors encoding the novel proteins, for example F64L-S175G-E222G-GFP, can be used for tagging plasmids and chromosomes.

- xi) Use as a reporter for bacterial detection by introducing the novel proteins into the genome of bacteriophages. By engineering the novel proteins, for example F64L-S175G-E222G-GFP, into the genome of a phage a diagnostic tool can be designed. F64L-S175G-E222G-GFP will be expressed only upon transfection of the genome into a living host. The host specificity is defined by the bacteriophage.

The invention is further illustrated by reference to the following examples and figures in which:

10

Figure 1 is the nucleotide Sequence of wtGFP (Chalfie et al, Science, (1994), 263, 802-5) and referred to herein as SEQ ID No.1.

Figure 2 is the corresponding amino acid sequence of wtGFP (Chalfie et al, Science, (1994), 263, 802-5) and referred to herein as SEQ ID No.2.

15 Figure 3 is the predicted amino acid sequence of F64L-S175G-E222G-GFP and referred to herein as SEQ ID No.3.

Figure 4 is the predicted amino acid sequence of F64L-S65T-S175G-GFP and referred to herein as SEQ ID No.4.

20 Figure 5 is a plot showing average fluorescence intensities of mutant GFPs according to the invention.

Figure 6 is a plot showing relative photodegradation of mutant GFPs according to the invention.

25 Figure 7 is a plot demonstrating the increase in the ratio of nuclear to cytoplasmic fluorescence intensity on translocation of P65-GFP from the cytoplasm to the nucleus of CHO-hir cells following agonist addition.

EXAMPLES1. Cloning of GFP gene and template vector construction

5

The GFP gene used in the present study was contained within the plasmid pGFP (Chalfie et al., Science, (1994), 263, 802-805; GenBank accession number U17997) obtained from Clontech Laboratories Inc. (Palo Alto, Ca, USA). The gene was amplified by PCR using Pfu polymerase  
 10 (Promega, Madison, WI, USA) according to recognised protocols (Saiki et al., Science, (1988), 239, 487-491). The sequences of primers used were:

GFP-1	5'-ggtacgggcccgccaccatgagtaaaggagaagaacttttcac	SEQ ID No.5
GFP-2	5'-ggtacgggttaaccggtttgtatagttcatccatg	SEQ ID No.6
GFP-3	5'-ggtacgggcccgccaccatgggatccaaaggagaagaacttttcac	SEQ ID No.7

Primer GFP-1 exhibits homology to the 5' region of the GFP gene and  
 15 contains a partial Kozak site (Kozak, M, Cell, (1986), 44, 283) prior to the start codon for efficient initiation of translation in mammalian systems. Primer GFP-2 exhibits homology to the 3' region of the GFP gene and contains an additional *AgeI* restriction enzyme site immediately prior to the stop codon to facilitate cloning of proteins by fusion to the C-terminus of  
 20 GFP. Primer GFP-3 is similar to primer GFP-1 exhibiting homology to the 5' region of the GFP gene, but contains an additional restriction site (*Bam*HI) immediately after the initiation codon to facilitate cloning of proteins by fusion to the N-terminus of GFP. Amplified products resulting from PCR reactions containing primers GFP-1 and GFP-2, and GFP-3 and GFP-2 were  
 25 tailed with a single 3'-deoxyadenosine using Taq polymerase (Amersham Pharmacia Biotech, Amersham, UK) and ligated into the TA cloning vector pTARGET (Promega) according to manufacturer's instructions. The correct



orientation relative to the CMV promoter and sequence of the insert was determined by automated DNA sequencing.

## 2. Generation of mutants of GFP

5

The following mutants of GFP were generated in the present study: F64L-GFP, V163A-GFP, S175G-GFP, E222G-GFP, F64L-E222G-GFP, F64L-V163A-GFP, F64L-S175G-GFP, V163A-S175G-GFP, V163A-E222G-GFP, S175G-E222G-GFP, F64L-S175G-E222G-GFP, V163A-S175G-E222G-GFP, 10 F64L-V163A-E222G-GFP, F64L-S65T-S175G-GFP, F64L-S65T-V163A-GFP. Mutants of the GFP gene (SEQ ID 3) construct within pTARGET (See Example 1) were generated using the QuikChange™ site-directed mutagenesis kit (Stratagene, La Jolla, Ca, USA) according to manufacturer's instructions. The sequences of primers used to generate F64L, S65T, V163A, S175G and 15 E222G single mutants have been documented in Table 1. Multiply-mutated GFP molecules were generated through successive mutagenesis reactions. All GFP mutant sequences were verified by automated sequencing.

Table 1

<u>Primer</u>	<u>Mutation</u>	<u>Sequence (5' - 3')</u>	<u>SEQ ID</u> <u>No.</u>
GFP-64f	F64L	ccaacacttgctactactctctcttatgggtgttcaat	8
GFP-64r	F64L	attgaacaccataagagagagtagtgacaagtgttgg	9
GFP-65f	S65T	ccaacacttgctactactctcacctatgggtgttcaatgctttca	10
GFP-65r	S65T	tgaaaagcattgaacaccataggtgagagtagtgacaagtgttgg	11
GFP-163f	V163A	gacaaacaaaagaatggaatcaaagccaacttcaaaattagacac	12
GFP-163r	V163A	gtgtcctaattttgaagttggctttgattccattctttgtttgtc	13
GFP-175f	S175G	caacattgaagatggaggcggtcaactagcagacc	14
GFP-175r	S175G	ggctctgctagttgaacgcctccatcttcaatgttg	15
GFP-222f	E222G	ccacatggctccttcttggtttgtaacagctgctgg	16
GFP-222r	E222G	ccagcagctgttacaaagccaagaaggaccatgtgg	17

20

3. Influence of individual mutations and combinations of F64L, S65T, V163A, S175G and E222G mutations upon GFP when expressed in mammalian cells

Plasmid DNA to be used for transfection was prepared for all GFP and EGFP constructs using the HiSpeed plasmid purification kit (Qiagen, Westberg, NL). DNA was diluted to 100 ng.  $\mu\text{l}^{-1}$  in 18-Megohm water (Sigma) and 1  $\mu\text{g}$  used for transfections. For 50-80% confluency on the day of transfection, HeLa cells were plated at a density of  $5 \times 10^4$ /well in 6-well plates and incubated overnight. A 1:3 (1  $\mu\text{g}$  : 3  $\mu\text{l}$ ) ratio of DNA to FuGene6 reagent (Roche) was used for each transient transfection reaction; 3  $\mu\text{l}$  FuGene6 was added to 87  $\mu\text{l}$  serum-free DMEM medium (Sigma) (containing penicillin/streptomycin, L-glutamine (GibcoBRL) and gently tapped to mix, then 10  $\mu\text{l}$  (1  $\mu\text{g}$ ) construct DNA was added and again gently mixed. The FuGene6:DNA complex was incubated at room temperature for 40 minutes then added dropwise directly to the cells without changing the medium, and the plates swirled for even distribution.

Fluorescence measurements were made 24 or 48 hours after transfection. Briefly, the cells were washed in phosphate-buffered saline, released with the addition of 2 drops of Trypsin (GibcoBRL) and resuspended in 1 ml of complete DMEM medium (containing penicillin/streptomycin, L-glutamine and foetal bovine serum (Sigma). The cells were vortexed and analysed on a FACS Calibur flow cytometer (Becton Dickinson & Co., NJ, USA) for characterisation of whole cell fluorescence, with excitation at 488 nm and emission viewed with fluorescence filter set 530/30nm (range 515-545 nm). 10,000 events were collected for each transfection and 6-10 replicates carried out for each construct. Average fluorescent intensities

from the FACS analysis were obtained as geometric means (mean fluorescence on log scale) and are shown in Figure 5.

#### 4. Purification of fluorescent proteins from *E. coli*

5

The gene for the mutant F64L-S175G-E222G-GFP (Example 2) was excised from pTARGET with *Bam*HI and *Sal*I and sub-cloned into the IPTG-inducible, GST-fusion vector pGEX-6P1 (Amersham Pharmacia Biotech). *E. coli* JM109 cells (Promega) containing an expression vector with the GST-GFP gene fusion were grown at 30°C to an OD<sub>600</sub> = 0.6 in 2x YT broth containing 100 µg/ml ampicillin. Protein expression was induced with IPTG (0.1 mM) and incubation continued for 16 hours. Cells were pelleted by centrifugation, resuspended in PBS and lysed by sonication (four 10 second bursts at 20 µm with intermittent cooling on ice). Cellular debris was removed by centrifugation and the lysate containing soluble GST-GFP fusion protein was purified using glutathione sepharose columns (Amersham Pharmacia Biotech). Protein was then exchanged and eluted in PBS using a PD10 column (Amersham Pharmacia Biotech). The presence of a single band of correct molecular weight in the protein preparation was confirmed by SDS-PAGE using 4-12% Bis-Tris NuPAGE gel electrophoresis (Invitrogen). To assess protein concentration and purity, the protein preparation was subjected, in duplicate, to acid hydrolysis and filtration before amino acid analysis by ion exchange chromatography using a Pharmacia alpha plus series II analyser.

25

The extinction coefficient (Table 2) was determined on a UV/vis spectrometer (Unicam). Quantum yield (Table 2) was determined according to the method documented by Patterson et al (Biophysical Journal, (1997), 73, 2782-2790). Samples of equal optical density at respective absorbance maxima were prepared, and diluted, in 10mM Tris.HCl pH 8 for the purified GFP preparation and a fluorescein reference standard (Molecular Probes).

30

Fluorescence emission was measured in the region 490 – 600nm using a LS50B luminescence spectrometer (Perkin Elmer) and results for the GFP preparation were compared directly to those for the fluorescein standard (QY = 0.85).

5

Table 2

<u>Protein</u>	<u>Absorbance peak (nm)</u>	<u>Extinction coefficient (M<sup>-1</sup> cm<sup>-1</sup>)</u>	<u>Emission peak (nm)</u>	<u>QY</u>
F64L-S175G- E222G-GFP	481	46213*	506	0.6*

\*Mean of two measurements

10 To evaluate the degree of photodegradation of the mutants F64L-S175G-E222G-GFP and F64L-E222G relative to wtGFP, 50ng of DNA was transfected into HeLa cells according to the method outlined in Example 3. For 50-80% confluency on the day of transfection, HeLa cells were plated at a density of  $5 \times 10^3$ /well in a ViewPlate™-96 (Packard, Meriden CT, USA).

15 Twenty-four hours after transfection, the cells were imaged live on a LEADseeker™ Cell Analysis System (Amersham Pharmacia Biotech) and bleached at high laser power (19.94mW) with a 488nm Argon laser (emission filter 535-45nm). Thirty-two individual images were taken over

20 260s with non-continuous illumination and all fluorescent proteins showed marked photodegradation as shown in Figure 6.

## 5. Measurement of NFκB translocation

25 NFκB is an activator of transcription and a component of signalling pathways which are responsive to a variety of inducers including cytokines, lymphokines, and some immunosuppressive agents.

The human NF $\kappa$ B P65 subunit gene (GenBank Accession number: M62399) was amplified using PCR according to recognised protocols (Saiki et al., Science, (1988), 239, 487-491). The sequences of primers used were:

5

NF $\kappa$ B-1	5'-ttttactcgagatggacgaactgttccccctca	SEQ ID No.18
NF $\kappa$ B-2	5'-ttttgaagcttgagctgatctgactcagcagg	SEQ ID No.19

The P65 subunit was fused to the N terminus of GFP (SEQ ID No.3) in the vector pCORON1000 (Amersham Pharmacia Biotech), under the control of a CMV promoter. This was transfected into CHO-hir cells using FuGene6 reagent (Roche) and standard transfection procedures and a stable cell line was produced containing the P65-GFP construct.

CHO-hir, P65-GFP cells were seeded into 96 well microtitre plates at a confluency of  $5 \times 10^3$  cells/well in DMEM media (Sigma) containing penicillin/streptomycin, L-glutamine (GibcoBRL) and incubated overnight at 37 °C. 1 hr before the assay was run, the media was removed and replaced with 100  $\mu$ l serum free DMEM/well. 100  $\mu$ l of 5  $\mu$ M DRAQ5 (Biostatus) in Krebs buffer was added to each well and incubated for 15 minutes at 37°C. The plate was then placed in the imager (LEADseeker Cell Analysis System) and wells were imaged at varying time points following addition of agonist (50 $\mu$ l of 40 ng/ml IL1 $\beta$ ). Translocation of the P65-GFP was observed from the cytoplasm to the nucleus following agonist addition. The ratio of nuclear/cytoplasmic fluorescence is shown in Figure 7.

25

Claims

1. A fluorescent protein which is derived from Green Fluorescent Protein  
5 (GFP) or any functional GFP analogue and has an amino acid sequence which is modified by amino acid substitution compared with the amino acid sequence of wild type Green Fluorescent Protein said modified fluorescent protein comprising:
- i) an amino acid substitution at position F64;
  - 10 ii) a single amino acid substitution at a position selected from the group consisting of positions S65 and E222; and
  - iii) an amino acid substitution at position S175;
- wherein said modified GFP has a different excitation spectrum and/or emission spectrum compared with wild type GFP.
- 15
2. A fluorescent protein according to claim 1 wherein the amino acid F at position 64 has been substituted by an amino acid selected from the group consisting of L, I, V, A and G.
- 20
3. A fluorescent protein according to claim 1 wherein the amino acid S at position 175 has been substituted by an amino acid selected from the group consisting of G, A, L, I and T.
- 25
4. A fluorescent protein according to claims 1 to 3 wherein the amino acid S at position 65 has been substituted by an amino acid selected from the group consisting of G, A, L, C, V, I and T.
- 30
5. A fluorescent protein according to claims 1 to 3 wherein the amino acid E at position 222 has been substituted by an amino acid selected from the group consisting of G, A, V, L, I, F, S, T, N and Q.

6. A fluorescent protein according to any of claims 1 to 5 selected from F64L-S175G-E222G-GFP and F64L-S65T-S175G-GFP.
7. A fluorescent protein according to any of claims 1 to 6 having an amino acid sequence which is modified by amino acid substitution compared with the amino acid sequence of wild type Green Fluorescent Protein having the sequence: SEQ ID No.2.
8. A fluorescent protein derived from Green Fluorescent Protein (GFP) and having the amino acid sequence as set forth in SEQ ID No.3.
9. A fluorescent protein derived from Green Fluorescent Protein (GFP) and having the amino acid sequence as set forth in SEQ ID No.4.
10. A fusion compound comprising a protein of interest fused to a fluorescent protein said fluorescent protein being a modified protein according to any of claims 1 to 9.
11. A nucleic acid molecule comprising a nucleotide sequence encoding a fluorescent protein which is derived from Green Fluorescent Protein (GFP) or any functional GFP analogue and has an amino acid sequence which is modified by amino acid substitution compared with the amino acid sequence of wild type Green Fluorescent Protein said modified fluorescent protein comprising:
- i) an amino acid substitution at position F64;
  - ii) a single amino acid substitution at a position selected from the group consisting of positions S65 and E222; and
  - iii) an amino acid substitution at position S175;
- wherein said modified GFP has a different excitation spectrum and/or emission spectrum compared with wild type GFP.

12. A nucleic acid according to claim 11 encoding a fluorescent protein having an amino acid sequence which is modified by amino acid substitution compared with the amino acid sequence of wild type Green Fluorescent Protein having the sequence: SEQ ID No.2.

5

13. A nucleic acid molecule according to claims 11 or 12 encoding a fluorescent protein having an amino acid sequence selected from the group consisting of SEQ ID No.3 and SEQ ID No.4.

10

14. A nucleic acid molecule comprising a nucleotide sequence encoding a fusion protein comprising a protein of interest fused to a fluorescent protein according to any one of claims 1 to 9.

15

15. An expression vector comprising suitable expression control sequences operably linked to a nucleic acid molecule according to any of claims 11 to 14.

20

16. A host cell transformed or transfected with a DNA construct comprising an expression vector according to claim 15.

17. The host cell according to claim 16 wherein said host cell is selected from the group consisting of a mammalian cell, a bacterial cell, a yeast cell and an insect cell.

25

18. A method for preparing a Green Fluorescent Protein (GFP) or a functional GFP analogue according to the present invention said method comprising cultivating a host according to claim 16 or claim 17 and obtaining therefrom the polypeptide expressed by said nucleotide sequence.

30

19. A method of measuring the expression of a protein of interest in a cell which method comprises:



- i) introducing into a cell a nucleic acid molecule comprising a nucleotide sequence encoding a fluorescent protein which is derived from Green Fluorescent Protein (GFP) or any functional GFP analogue according to any one of claims 1 to 9 said nucleic acid molecule being operably linked to and  
5 under the control of an expression control sequence which moderates expression of said protein of interest;
- ii) culturing said cell under conditions suitable for the expression of said protein of interest; and
- iii) detecting the fluorescence emission of said Green Fluorescent Protein  
10 (GFP) or a functional GFP analogue as a means of measuring the expression of said protein of interest.

20. A method of determining the cellular and/or extracellular localisation of a protein of interest which method comprises:

- 15 i) introducing into a cell a nucleic acid molecule comprising a nucleotide sequence encoding a fluorescent protein which is derived from Green Fluorescent Protein (GFP) or any functional GFP analogue according to any one of claims 1 to 9 fused to a nucleotide sequence encoding a protein of interest, said nucleic acid molecule being operably linked to and under the  
20 control of a suitable expression control sequence;
- ii) culturing said cell under conditions suitable for the expression of said protein of interest; and
- iii) determining the cellular and/or extracellular localisation of said protein of interest by detecting the fluorescence emission by optical means.

25

21. A method of comparing the effect of one or more test substance(s) on the expression and/or localisation of one or more different protein(s) of interest in a cell which method comprises:

- i) introducing into a cell:
- 30 a) a nucleic acid molecule comprising a nucleotide sequence encoding a Green Fluorescent Protein (GFP) or a functional GFP analogue according to

- any one of claims 1 to 9 optionally fused to a nucleotide sequence encoding a first protein of interest, said nucleic acid molecule being operably linked to and under the control of a first expression control sequence; and optionally,
- b) at least one different nucleic acid molecule encoding a protein reporter molecule optionally fused to a different protein of interest, each said nucleic acid molecule being operably linked to and under the control of a second expression control sequence wherein said protein reporter molecule has or is capable of generating an emission signal which is spectrally distinct from that of said Green Fluorescent Protein (GFP) or functional GFP analogue;
- ii) culturing said cells under conditions suitable for the expression of said protein(s) of interest in the presence and absence of said test substance(s);
- iii) determining the expression and/or localisation of said protein(s) of interest in said cells by detecting the fluorescence emission by optical means; and
- iv) comparing the fluorescence emission obtained in the presence and absence of said test substance(s) to determine the effect of said test substance(s) on the expression and/or localisation of said protein(s) of interest.
22. The method according to claim 21 wherein samples of said cells in a fluid medium are introduced into separate vessels for each of said test substances to be studied.

1/7Nucleotide Sequence of wtGFP (Chalfie et al, Science, (1994), 263, 802-5):SEQ ID No.1

```
atg agt aaa gga gaa gaa ctt ttc act gga gtt gtc cca att ctt gtt 48
gaa tta gat ggt gat gtt aat ggg cac aaa ttt tct gtc agt gga gag 96
ggt gaa ggt gat gca aca tac gga aaa ctt acc ctt aaa ttt att tgc 144
act act gga aaa cta cct gtt cca tgg cca aca ctt gtc act act ttc 192
tct tat ggt gtt caa tgc ttt tca aga tac cca gat cat atg aaa cgg 240
cat gac ttt ttc aag agt gcc atg ccc gaa ggt tat gta cag gaa aga 288
act ata ttt ttc aaa gat gac ggg aac tac aag aca cgt gct gaa gtc 336
aag ttt gaa ggt gat acc ctt gtt aat aga atc gag tta aaa ggt att 384
gat ttt aaa gaa gat gga aac att ctt gga cac aaa ttg gaa tac aac 432
tat aac tca cac aat gta tac atc atg gca gac aaa caa aag aat gga 480
atc aaa gtt aac ttc aaa att aga cac aac att gaa gat gga agc gtt 528
caa cta gca gac cat tat caa caa aat act cca att ggc gat ggc cct 576
gtc ctt tta cca gac aac cat tac ctg tcc aca caa tct gcc ctt tcg 624
aaa gat ccc aac gaa aag aga gac cac atg gtc ctt ctt gag ttt gta 672
aca gct gct ggg att aca cat ggc atg gat gaa cta tac aaa tag 717
```

2/7Amino Acid Sequence of wtGFP (Chalfie et al, Science, (1994), 263, 802-5SEQ ID No.2

```

Met Ser Lys Gly Glu Glu Leu Phe Thr Gly Val Val Pro Ile Leu Val
1          5          10          15
Glu Leu Asp Gly Asp Val Asn Gly His Lys Phe Ser Val Ser Gly Glu
          20          25          30
Gly Glu Gly Asp Ala Thr Tyr Gly Lys Leu Thr Leu Lys Phe Ile Cys
          35          40          45
Thr Thr Gly Lys Leu Pro Val Pro Trp Pro Thr Leu Val Thr Thr Phe
          50          55          60
Ser Tyr Gly Val Gln Cys Phe Ser Arg Tyr Pro Asp His Met Lys Arg
65          70          75          80
His Asp Phe Phe Lys Ser Ala Met Pro Glu Gly Tyr Val Gln Glu Arg
          85          90          95
Thr Ile Phe Phe Lys Asp Asp Gly Asn Tyr Lys Thr Arg Ala Glu Val
          100          105          110
Lys Phe Glu Gly Asp Thr Leu Val Asn Arg Ile Glu Leu Lys Gly Ile
          115          120          125
Asp Phe Lys Glu Asp Gly Asn Ile Leu Gly His Lys Leu Glu Tyr Asn
130          135          140
Tyr Asn Ser His Asn Val Tyr Ile Met Ala Asp Lys Gln Lys Asn Gly
145          150          155          160
Ile Lys Val Asn Phe Lys Ile Arg His Asn Ile Glu Asp Gly Ser Val
          165          170          175
Gln Leu Ala Asp His Tyr Gln Gln Asn Thr Pro Ile Gly Asp Gly Pro
          180          185          190
Val Leu Leu Pro Asp Asn His Tyr Leu Ser Thr Gln Ser Ala Leu Ser
          195          200          205
Lys Asp Pro Asn Glu Lys Arg Asp His Met Val Leu Leu Glu Phe Val
210          215          220
Thr Ala Ala Gly Ile Thr His Gly Met Asp Glu Leu Tyr Lys
225          230          235

```

Predicted Amino Acid Sequence of F64L-S175G-E222G-GFP:

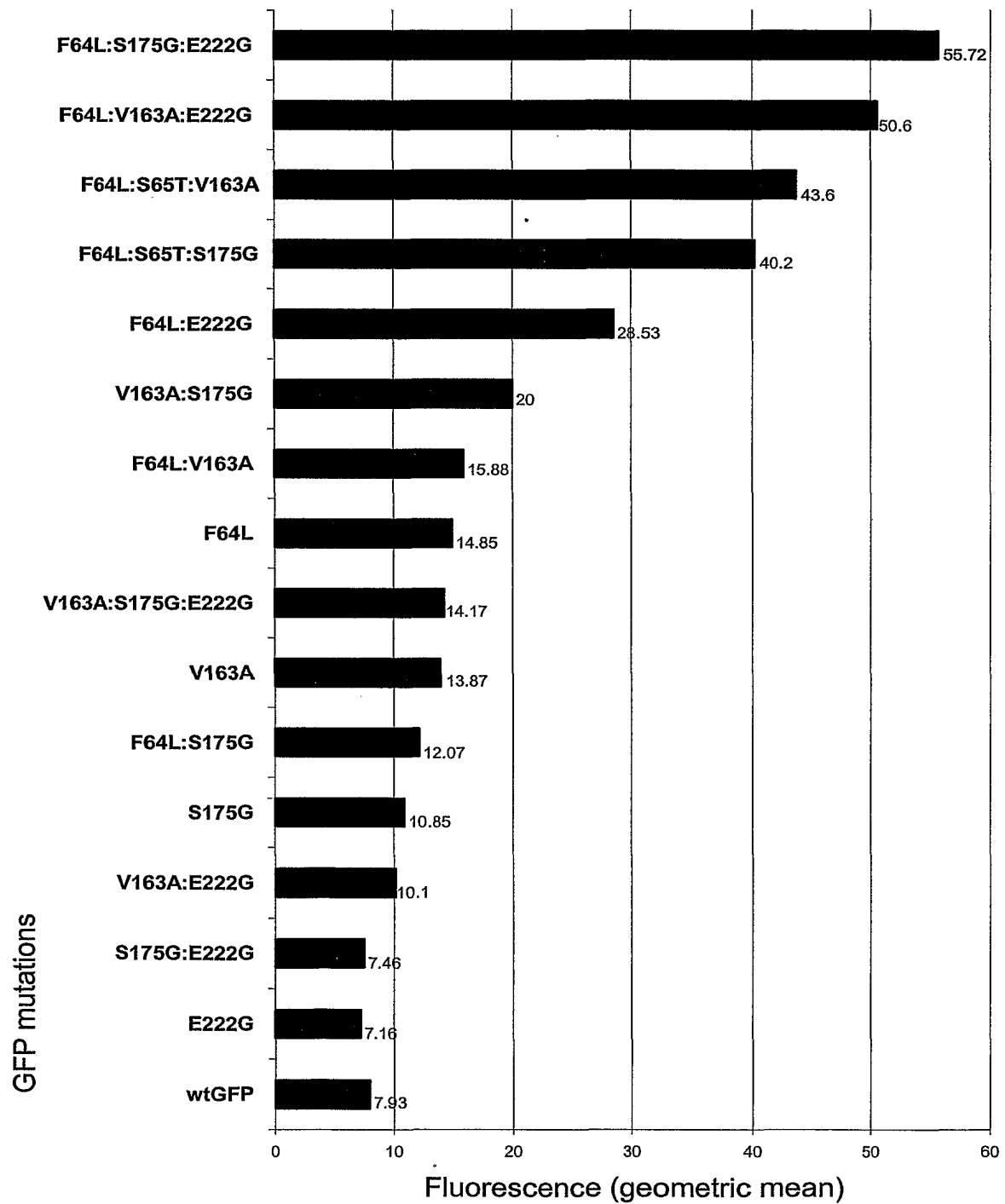
SEQ ID No.3

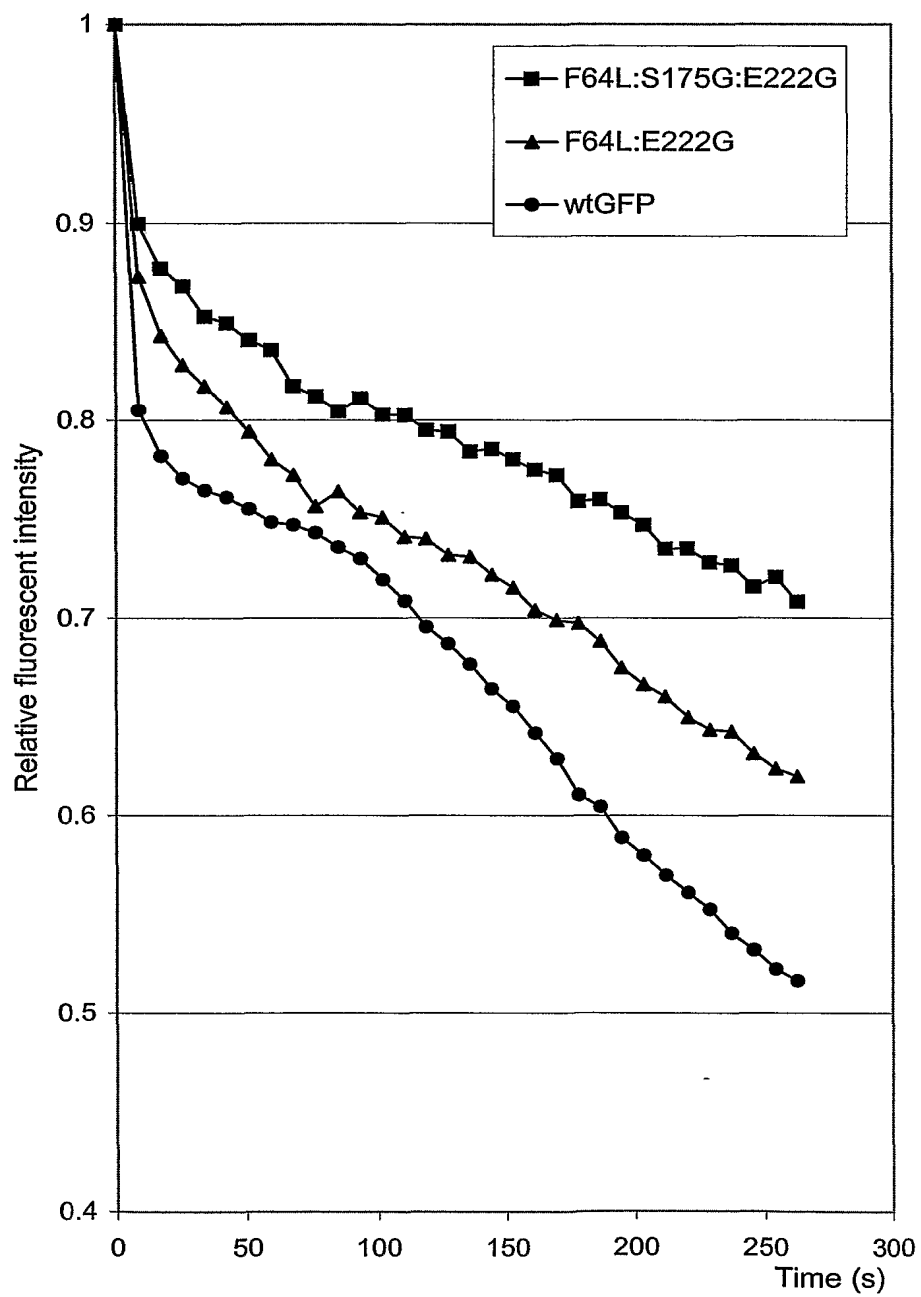
Met 1	Ser	Lys	Gly	Glu 5	Glu	Leu	Phe	Thr	Gly 10	Val	Val	Pro	Ile	Leu	Val
Glu	Leu	Asp	Gly 20	Asp	Val	Asn	Gly	His 25	Lys	Phe	Ser	Val	Ser	Gly	Glu
Gly	Glu	Gly 35	Asp	Ala	Thr	Tyr	Gly 40	Lys	Leu	Thr	Leu	Lys 45	Phe	Ile	Cys
Thr	Thr 50	Gly	Lys	Leu	Pro	Val 55	Pro	Trp	Pro	Thr	Leu 60	Val	Thr	Thr	Leu
Ser 65	Tyr	Gly	Val	Gln	Cys 70	Phe	Ser	Arg	Tyr	Pro 75	Asp	His	Met	Lys	Arg
His	Asp	Phe	Phe	Lys 85	Ser	Ala	Met	Pro	Glu 90	Gly	Tyr	Val	Gln	Glu	Arg
Thr	Ile	Phe	Phe 100	Lys	Asp	Asp	Gly	Asn 105	Tyr	Lys	Thr	Arg	Ala	Glu	Val
Lys	Phe	Glu 115	Gly	Asp	Thr	Leu	Val 120	Asn	Arg	Ile	Glu	Leu 125	Lys	Gly	Ile
Asp	Phe 130	Lys	Glu	Asp	Gly	Asn 135	Ile	Leu	Gly	His	Lys 140	Leu	Glu	Tyr	Asn
Tyr 145	Asn	Ser	His	Asn	Val 150	Tyr	Ile	Met	Ala	Asp 155	Lys	Gln	Lys	Asn	Gly 160
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Gln	Leu	Ala	Asp 180	His	Tyr	Gln	Gln	Asn 185	Thr	Pro	Ile	Gly	Asp	Gly	Pro
Val	Leu	Leu 195	Pro	Asp	Asn	His	Tyr 200	Leu	Ser	Thr	Gln	Ser 205	Ala	Leu	Ser
Lys	Asp 210	Pro	Asn	Glu	Lys	Arg 215	Asp	His	Met	Val	Leu 220	Leu	Gly	Phe	Val
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### Predicted Amino Acid Sequence of F64L-S65T-S175G-GFP:

SEQ ID No.4

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Glu	Leu	Asp	Gly 20	Asp	Val	Asn	Gly	His 25	Lys	Phe	Ser	Val	Ser 30	Gly	Glu
Gly	Glu	Gly 35	Asp	Ala	Thr	Tyr	Gly 40	Lys	Leu	Thr	Leu	Lys 45	Phe	Ile	Cys
Thr	Thr 50	Gly	Lys	Leu	Pro	Val 55	Pro	Trp	Pro	Thr	Leu 60	Val	Thr	Thr	Leu
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His	Asp	Phe	Phe	Lys 85	Ser	Ala	Met	Pro	Glu 90	Gly	Tyr	Val	Gln	Glu 95	Arg
Thr	Ile	Phe	Phe 100	Lys	Asp	Asp	Gly	Asn 105	Tyr	Lys	Thr	Arg	Ala 110	Glu	Val
Lys	Phe	Glu 115	Gly	Asp	Thr	Leu	Val 120	Asn	Arg	Ile	Glu	Leu 125	Lys	Gly	Ile
Asp	Phe 130	Lys	Glu	Asp	Gly	Asn 135	Ile	Leu	Gly	His	Lys 140	Leu	Glu	Tyr	Asn
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Ile	Lys	Val	Asn	Phe 165	Lys	Ile	Arg	His	Asn 170	Ile	Glu	Asp	Gly	Gly 175	Val
Gln	Leu	Ala	Asp 180	His	Tyr	Gln	Gln	Asn 185	Thr	Pro	Ile	Gly	Asp 190	Gly	Pro
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Lys	Asp 210	Pro	Asn	Glu	Lys	Arg 215	Asp	His	Met	Val	Leu 220	Leu	Glu	Phe	Val
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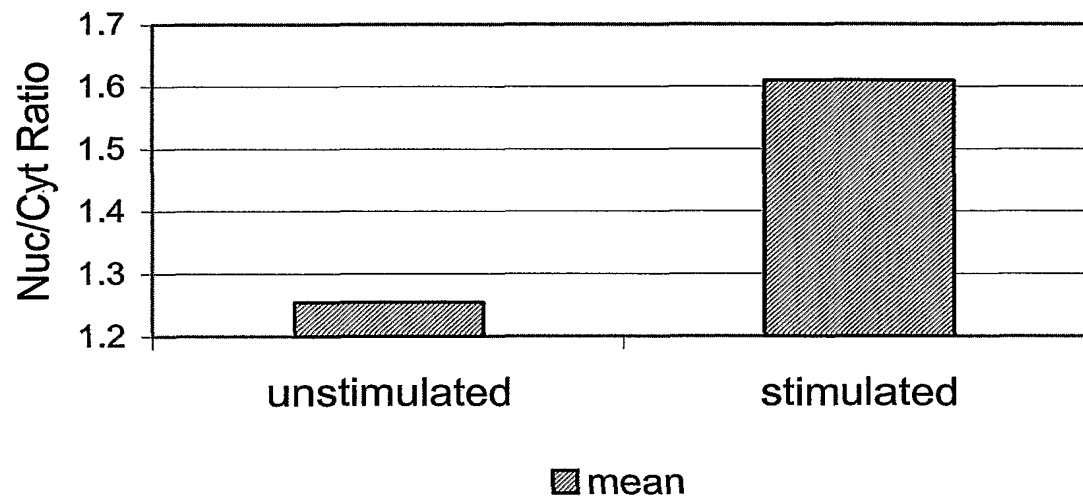
Flow cytometry of GFP mutations

Photobleaching of GFP mutations



7/7

Live Cell CHO-HIR NF $\kappa$ B Assay  
P65-tri GFP Assay T = 30 mins



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 35 40 45

Thr Thr Gly Lys Leu Pro Val Pro Trp Pro Thr Leu Val Thr Thr Phe  
 50 55 60

Ser Tyr Gly Val Gln Cys Phe Ser Arg Tyr Pro Asp His Met Lys Arg  
 65 70 75 80

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 85 90 95

Thr Ile Phe Phe Lys Asp Asp Gly Asn Tyr Lys Thr Arg Ala Glu Val  
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Lys Phe Glu Gly Asp Thr Leu Val Asn Arg Ile Glu Leu Lys Gly Ile  
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Asp Phe Lys Glu Asp Gly Asn Ile Leu Gly His Lys Leu Glu Tyr Asn  
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Ile Lys Val Asn Phe Lys Ile Arg His Asn Ile Glu Asp Gly Ser Val  
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Gln Leu Ala Asp His Tyr Gln Gln Asn Thr Pro Ile Gly Asp Gly Pro  
 180 185 190

Val Leu Leu Pro Asp Asn His Tyr Leu Ser Thr Gln Ser Ala Leu Ser  
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Thr Thr Gly Lys Leu Pro Val Pro Trp Pro Thr Leu Val Thr Thr Leu  
 50 55 60

Ser Tyr Gly Val Gln Cys Phe Ser Arg Tyr Pro Asp His Met Lys Arg  
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His Asp Phe Phe Lys Ser Ala Met Pro Glu Gly Tyr Val Gln Glu Arg  
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Thr Ile Phe Phe Lys Asp Asp Gly Asn Tyr Lys Thr Arg Ala Glu Val  
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Lys Phe Glu Gly Asp Thr Leu Val Asn Arg Ile Glu Leu Lys Gly Ile  
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Asp Phe Lys Glu Asp Gly Asn Ile Leu Gly His Lys Leu Glu Tyr Asn  
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Tyr Asn Ser His Asn Val Tyr Ile Met Ala Asp Lys Gln Lys Asn Gly  
 145 150 155 160

Ile Lys Val Asn Phe Lys Ile Arg His Asn Ile Glu Asp Gly Gly Val  
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Gln Leu Ala Asp His Tyr Gln Gln Asn Thr Pro Ile Gly Asp Gly Pro  
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Val Leu Leu Pro Asp Asn His Tyr Leu Ser Thr Gln Ser Ala Leu Ser  
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Lys Asp Pro Asn Glu Lys Arg Asp His Met Val Leu Leu Gly Phe Val  
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 35 40 45

Thr Thr Gly Lys Leu Pro Val Pro Trp Pro Thr Leu Val Thr Thr Leu  
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Thr Tyr Gly Val Gln Cys Phe Ser Arg Tyr Pro Asp His Met Lys Arg  
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His Asp Phe Phe Lys Ser Ala Met Pro Glu Gly Tyr Val Gln Glu Arg  
 85 90 95

Thr Ile Phe Phe Lys Asp Asp Gly Asn Tyr Lys Thr Arg Ala Glu Val  
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Lys Phe Glu Gly Asp Thr Leu Val Asn Arg Ile Glu Leu Lys Gly Ile

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## INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 01/04363

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 C07K14/435 C12N15/00 C12N15/62 C12N15/10 G01N33/00  
C12Q1/68

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 C07K C12N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

CHEM ABS Data, BIOSIS, EPO-Internal

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6 054 321 A (ORMOE MATS F ET AL) 25 April 2000 (2000-04-25) examples, claims, column 14 ----	1-22
Y	WO 00 08054 A (PEPPERKOK RAINER ;IMP CANCER RES TECH (GB); GELEY STEFAN (GB); BAS) 17 February 2000 (2000-02-17) S175G, claim 1, Table 1, ----- -/--	1-22

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

## ° Special categories of cited documents :

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
- \*E\* earlier document but published on or after the international filing date
- \*L\* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- \*O\* document referring to an oral disclosure, use, exhibition or other means
- \*P\* document published prior to the international filing date but later than the priority date claimed

- \*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- \*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- \*Y\* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- \* & \* document member of the same patent family

Date of the actual completion of the international search

28 May 2002

Date of mailing of the international search report

06/06/2002

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
 NL - 2280 HV Rijswijk  
 Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
 Fax: (+31-70) 340-3016

Authorized officer

Kronester-Frei, A

## INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 01/04363

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	BREJC KATJUSA ET AL: "Structural basis for dual excitation and photoisomerization of the Aequorea victoria green fluorescent protein" PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF USA, NATIONAL ACADEMY OF SCIENCE. WASHINGTON, US, vol. 94, no. 6, March 1997 (1997-03), pages 2306-2311, XP002186298 ISSN: 0027-8424 whole article, esp. abstract, Fig. 2 ---	1-22
A	US 6 150 176 A (REMINGTON S JAMES ET AL) 21 November 2000 (2000-11-21) column 39, claims ---	1-22
A	WO 97 42320 A (US HEALTH) 13 November 1997 (1997-11-13) examples, claims ---	1-22
A	CORMACK B P ET AL: "FACS-OPTIMIZED MUTANTS OF THE GREEN FLUORESCENT PROTEIN (GFP)" GENE: AN INTERNATIONAL JOURNAL ON GENES AND GENOMES, ELSEVIER SCIENCE PUBLISHERS, BARKING, GB, vol. 173, no. 1, 1 July 1996 (1996-07-01), pages 33-38, XP002037756 ISSN: 0378-1119 abstract ---	1-22
E	WO 01 98338 A (BIOIMAGE AS ;BJORN SARA P (DK); PAGLIARO LEN (DK); THASTRUP OLE (D) 27 December 2001 (2001-12-27) Tables, jf-GFP-F64L/E222G -----	1-22

## INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB 01/04363

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
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			US 6077707 A	20-06-2000
			AU 727088 B2	30-11-2000
			AU 4327797 A	06-03-1998
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			JP 2001506842 T	29-05-2001
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WO 0008054	A	17-02-2000	AU 5429199 A	28-02-2000
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			EP 1102791 A1	30-05-2001
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			AU 734239 B2	07-06-2001
			AU 2829097 A	26-11-1997
			CA 2184763 A1	09-11-1997
			EP 0900274 A1	10-03-1999
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			WO 0198338 A2	27-12-2001
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